# OPERATING INSTRUCTIONS

for

# TYPE 874-UB BALUN

GENERAL RADIO COMPANY

CAMBRIDGE 39 MASSACHUSETTS

NEW YORK CHICAGO LOS ANGELES

U. S. A.

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## TABLE OF CONTENTS


SPECIFICATIONS

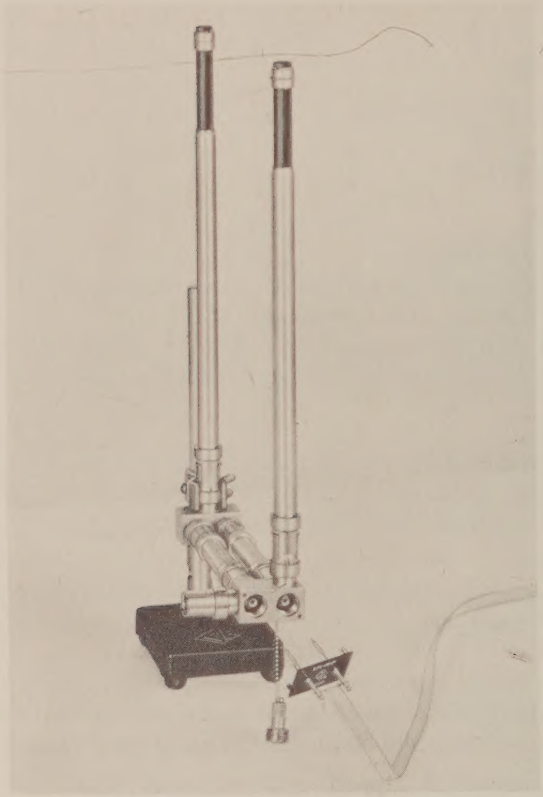
1.0 DESCRIPTION

1.1 GENERAL DESCRIPTION . . . . . 1
1.2 THEORY . . . . . 2
1.3 CONSTRUCTION . . . . . 5

2.0 OPERATION

2.1 FREQUENCY RANGE . . . . . 5
2.2 METHOD OF ADJUSTMENT OF TUNING ELEMENTS . . . . 5
2.3 CONNECTION OF THE UNKNOWN . . . . . 6
2.4 MEASUREMENT OF BALANCED CIRCUITS USING THE TYPE 1602-A ADMITTANCE METER ON A 300-OHM LINE . . . . . 8
2.41 Example . . . . . 10
2.5 MEASUREMENT OF THE IMPEDANCE OF BALANCED CIRCUITS USING THE TYPE 1602-A ADMITTANCE METER AND THE TYPE 874-LK CONSTANT IMPEDANCE ADJUSTABLE LINE . . . . 12
2.51 Example . . . . . 14
2.6 DETERMINATION OF IMPEDANCE AT OTHER POINTS ALONG THE 300-OHM LINE . . . . . 16
2.61 Line Length Correction Using the Smith Chart . . . . . 16
2.62 Line-Length Corrections Using Transmission-Line Equations . 17
2.63 Determination of the Electrical Length of the Balanced Line . 17
2.7 DETERMINATION OF VSWR ON BALANCED LINE 18
2.8 BALANCED-LINE MEASUREMENTS USING THE TYPE 874-LB SLOTTED LINE . . . . . 20
2.81 Example . . . . . 22
2.9 MEASUREMENT OF BALANCED LINES HAVING CHARACTERISTIC IMPEDANCES DIFFERING FROM 300-OHMS . . . . . 22
2.10 USE OF THE BALUN TO OBTAIN A BALANCED VOLTAGE SOURCE . . . . . 23
2.11 EFFECT OF UNBALANCE IN CIRCUIT UNDER TEST . . . 23


Coaxial parts, oscillators, and other accessories mentioned in this Instruction Book are available from the General Radio Company. Complete descriptions with prices will be forwarded upon request.



**View of the Type 874-UB Balun with two Type 874-D20 Adjustable Stubs and two Type 874-L10 Air Lines as tuning elements. The 300-ohm connector is shown in the foreground. The balun is shown mounted on a Type 874-Z Stand.**

## SPECIFICATIONS

**Frequency Range:** 50 to 1000 Mc with proper accessories.

**Accessories Supplied:** One Type 874-UB-P1 300-ohm Terminal, one Type 874-WN3 Short Circuit Termination, one Type 874-WO3 Open-Circuit Termination.

**Other Accessories Recommended:** One Type 874-LK Constant-Impedance Adjustable Line (when used with the Type 1602-A Admittance Meter), and one Type 874-Z Stand.

U. S. Patent Nos. 2,125,816 and 2,548,457.

# Operating Instructions for Type 874-UB Balun

## 1.0 DESCRIPTION

### 1.1 GENERAL DESCRIPTION

The Type 874-UB Balun is a balanced-to-unbalanced coaxial transformer for use with grounded measuring systems to measure the impedance of balanced circuits at high frequencies. The balun is very flexible in application and can be used over a wide frequency range. It is made tunable, so that the best possible accuracy can be obtained at any frequency within its range.

The balanced-to-unbalanced transformation is obtained by using a semi-artificial half-wave coaxial line made up of two sections of 50-ohm coaxial line and two shunt tuning elements as shown in Figure 1. At the higher frequencies, short-circuited Type 874-D20 Adjustable Stubs are used as tuning elements, and at the lower frequencies Type 874-VC Variable Capacitors are used.

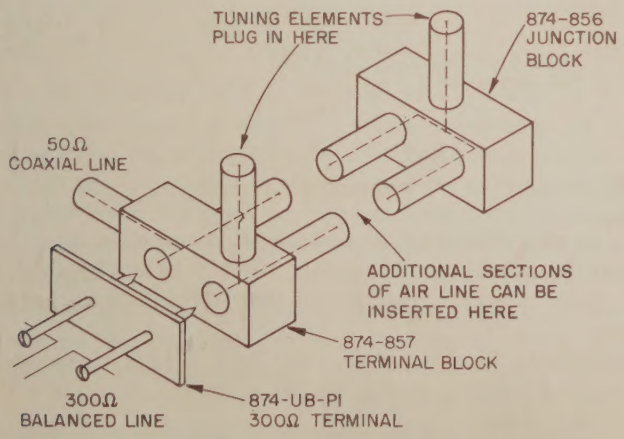

TUNING ELEMENTS PLUG IN HERE
874-856 JUNCTION BLOCK
50Ω COAXIAL LINE
ADDITIONAL SECTIONS OF AIR LINE CAN BE INSERTED HERE
874-857 TERMINAL BLOCK
300Ω BALANCED LINE
874-UB-PI 300Ω TERMINAL

Figure 1. Schematic showing the functional arrangement of the balun.

The impedance seen at the end of the coaxial measuring line is one-fourth the impedance appearing across the balanced end of the transformer. The coaxial admittance is four times the balanced admittance.

A removable terminal assembly is provided, which makes it possible to connect 300-ohm balanced lines to the balun without introducing an appreciable discontinuity in the line due to terminal capacitance and conductance. The terminals are designed in such a manner that the terminal capacitance and inductances form a short section of balanced transmission line having a 300-ohm characteristic impedance. Hence the terminal reactances only increase the length of the balanced line and have no effect on the VSWR. Terminals for balanced lines having other impedances can be constructed, or the 300-ohm terminals can be used and corrections made.

The balun is well suited to use with the Type 1602-A Admittance Meter and the Type 874-LB Slotted Line, as well as with other impedance measuring devices. When the admittance meter is the measuring device, the use of a Type 874-LK Constant-Impedance Adjustable Line is recommended to make the meter direct reading in the impedance of the balanced circuit.

This balun is not too well suited to converting a signal generator having an unbalanced 50-ohm output impedance to a 300-ohm balanced device, because the impedance transformation is 4 to 1, thereby producing a 200-ohm output impedance. Also the tuning cannot be easily accomplished without using an impedance measuring device. Where the impedance level is not important, however, it can be used satisfactorily.

## 1.2 THEORY

The voltage appearing at the load end of a half-wavelength section of transmission line is equal in magnitude and $180^{\circ}$ out of phase with the input voltage independent of the load impedance. Also the impedance appearing at the input terminals will be equal to the load impedance. If a half-wavelength line is connected as shown in Figure 2, it provides a balanced output from an unbalanced input. The voltage from either balanced terminal to ground will be equal to the unbalanced input voltage, and the voltage between the two balanced terminals will be twice the input voltage. The impedance seen at the unbalanced input will be one-quarter of the impedance appearing across the balanced terminals.

The use of an actual half-wavelength section of line restricts the frequency range greatly unless many different lengths of line are used. A much wider frequency range can be obtained by using a semi-artificial or loaded half-wave line as shown in Figure 3.

The artificial line can be adjusted by means of the adjustable stub lines to be effectively a half-wavelength long over a wide band of frequencies.

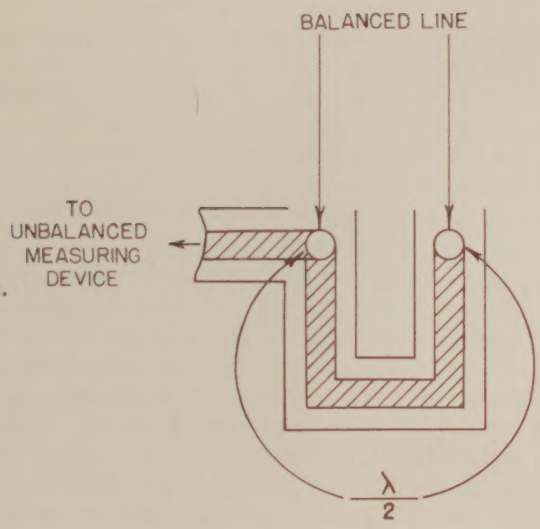



Figure 2.

A method of connecting a half-wave line to form a balun.

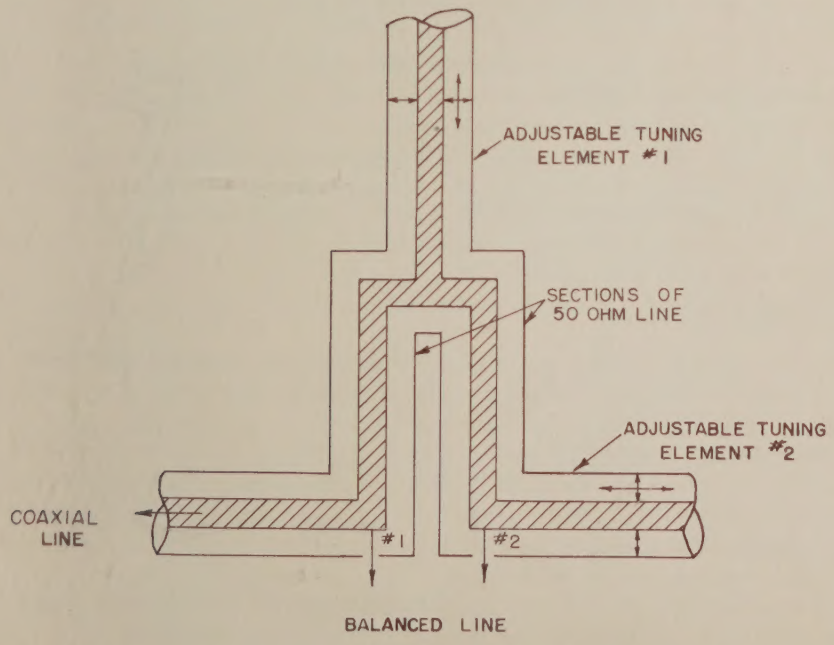



Figure 3. A balun using a semi-artificial or loaded half-wave line.

The operation of the artificial line can perhaps be most easily understood by considering the lumped circuit equivalent shown in Figure 4a. Here the series inductive reactance is twice the shunt capacitive reactance. If the line is truly effectively a half-wavelength long, a short circuit will appear at the input terminals when the output terminals are short-circuited, and an open circuit will appear at the input terminals when the output terminals are open-circuited. In the shorted case, the inductance nearest the load appears directly in parallel with the capacitance at the center of the line as shown in Figure 4b. The parallel combination of these reactances produces a reactance of $-2$ which in series is with the $+2$ reactance near the output. The resultant input impedance is zero. For the open-circuit case the inductance and reactance nearest the load are in series and appear in parallel with the center capacitance as shown in Figure 4c. The effective impedance of this combination is infinite. The input impedance is the reactance of the inductor nearest the input in series with the infinite impedance and, of course, is infinite. The roles of the inductance and capacitance can be interchanged and the same performance obtained.

A rigorous proof of the half-wave equivalence is too lengthy to include here, but the preceding discussion is adequate to show that the artificial line does have the properties of a true half-wave line.

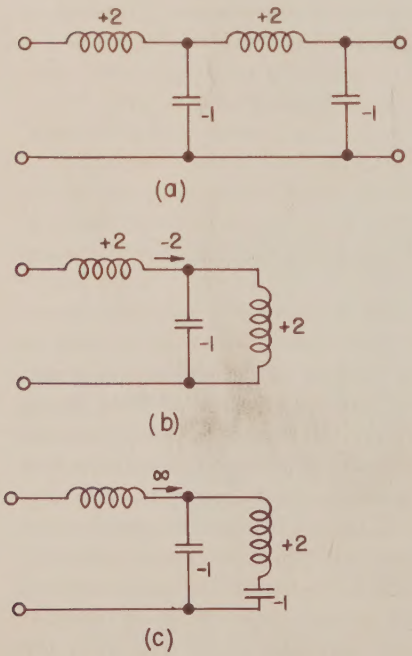



Figure 4.

Approximate equivalent circuit of the semi-artificial half-wave line.

Equivalent circuit with the right-hand terminals short-circuited.

Equivalent circuit with the right-hand terminals open-circuited.

## 1.3 CONSTRUCTION

The basic Type 874-UB Balun consists of three parts as shown in Figure 1, the Type 874-856 Junction Block, the Type 874-857 Terminal Block and the Type 874-UB-PI 300-ohm Terminal. The Junction and Terminal Blocks can be plugged directly together by means of a pair of Type 874 Coaxial Connectors, or sections of Type 874-L Air Line can be inserted between the two units. Shunt tuning elements of the appropriate type are plugged into the Type 874 Connector located on the top of each block. The balanced line under test should be connected to the Type 874-UB-PI 300-ohm Terminal Unit as shown in Figure 5. The terminal unit plugs into the spring jacks in the ends of the center conductors as indicated in Figure 1.

# 2.0 OPERATION

## 2.1 FREQUENCY RANGE

The frequency range over which the balun can be adjusted is dependent on the range of adjustment of the stub lines used and the length of air line connected between the two balun elements. Figure 6 is a chart showing the range of adjustment with various combinations of elements.

## 2.2 METHOD OF ADJUSTMENT OF TUNING ELEMENTS

The balun is adjusted for proper operation at a particular frequency by means of adjustable stub lines or variable capacitors. In Figure 3 the balanced terminal, Number 2, not directly connected to the coaxial measuring line, is short-circuited by screwing the plug, attached to the balun by the chain, into the hole in the terminal block. The center tuning element, Number 1, is then adjusted until a short circuit appears at the other balanced terminal, Number 1, which is connected to the center conductor of the coaxial line from the measuring device. The plug is then removed and stub Number 2 is adjusted until an open circuit appears at balanced terminal Number 1.

The impedance from Number 1 terminal to ground is measured by an admittance meter, slotted line, or other impedance measuring device. In adjusting the balun the measuring device is first set to balance to a null when a short circuit appears at balanced terminal Number 1. Then tuning element Number 1 is adjusted until a null is obtained with balanced terminal Number 2 short-circuited. The measuring device is then set to balance to a null when an open circuit appears at balanced terminal Number 1, and tuning element Number 2 adjusted for a null with balanced terminal Number 2 open-circuited. When this procedure is carried out, the balun is adjusted properly.

Actually most measuring devices will not measure the impedance at terminal Number 1 directly, but measure it at some point along the coaxial line joining the balun and the measuring instrument. For instance, the

Type 1602-A Admittance Meter measures admittance or impedance at a point directly under the center of the multiplier loop. The measured impedance or admittance must then be corrected for the length of 50-ohm line between the point of measurement and balanced terminal Number 1 in order to obtain the true value of the impedance. This correction can be made using transmission-line equations or preferably Smith charts. (See Paragraph 2.4.)

In setting up the balun the correction procedure for determining the setting of the measuring device corresponding to an open or short circuit at balanced terminal Number 1 can be eliminated if the Type 874-WN3 Short Circuit Termination and Type 874-WO3 Open Circuit Termination are used. When these units are connected to the measuring device, they produce an open or short circuit at a point along the line corresponding to the position of balanced terminal Number 1 when the balun is connected. The equivalent open- and short-circuit settings of the measuring device can therefore be determined by plugging in the proper unit.

## 2.3 CONNECTION OF UNKNOWN

The balanced circuit to be measured is connected to balanced terminals Numbers 1 and 2 of the balun. In order to minimize errors, the line under measurement should have its characteristic impedance remain constant right up to the terminals of the balun. The line impedance may be appreciably affected by the proximity of the grounded balun block and hence for the most accurate results, a terminal unit designed for the line to be used for connection of the line to the balun. The unit supplied, shown in Figure 5, is designed for 300-ohm twin lead. This terminal unit is equivalent to a short length of 300-ohm line and compensates for effects of the balun block. Therefore, when it is used for measurements on 300-ohm twin lead, it insures that the 300-ohm characteristic impedance extends directly to the balun terminals.

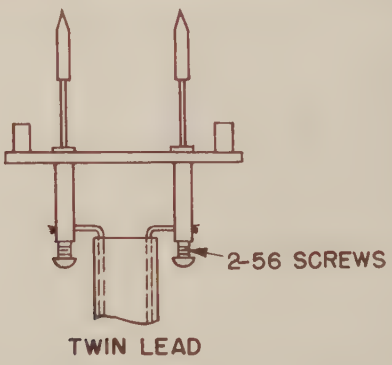



Figure 5. Sketch of the Type 874-UB-P1 300-ohm Terminal Unit showing the method of connecting the balanced line.

If desired, balanced lines having other characteristic impedances can be measured using the 300-ohm terminals if the equivalent length of 300-ohm line in the terminal unit is corrected for – using a Smith chart or transmission-line equations – when determining the unknown impedance. (See Paragraph 2.9.)

The impedance seen at the coaxial connection to the balun is one-fourth the actual balanced impedance. If the impedance is measured using a device such as an admittance meter, which measures the admittance at a point along the line some distance from the point of connection of the coaxial line to the balanced line at terminal Number 1, the measured admittance must be corrected for length of 50-ohm line between the points in question, using a Smith chart or transmission-line equations. (See Figure 7 and Paragraphs 2.4 and 2.41.

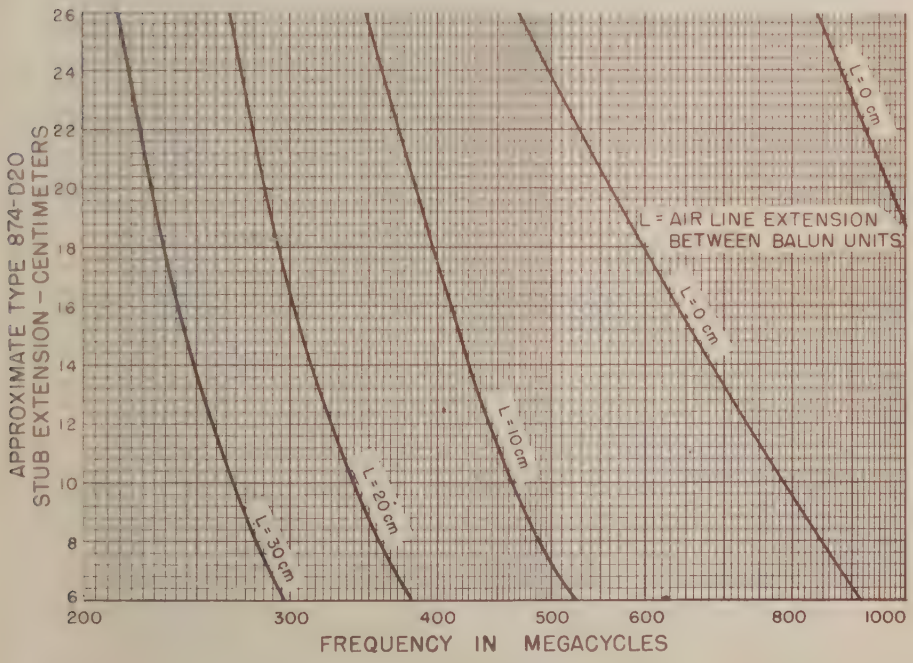



Figure 6a. Tuning ranges of the Type 874-UB Balun with the new style, calibrated Type 874-D20 Adjustable Stubs used as shunt tuning elements.

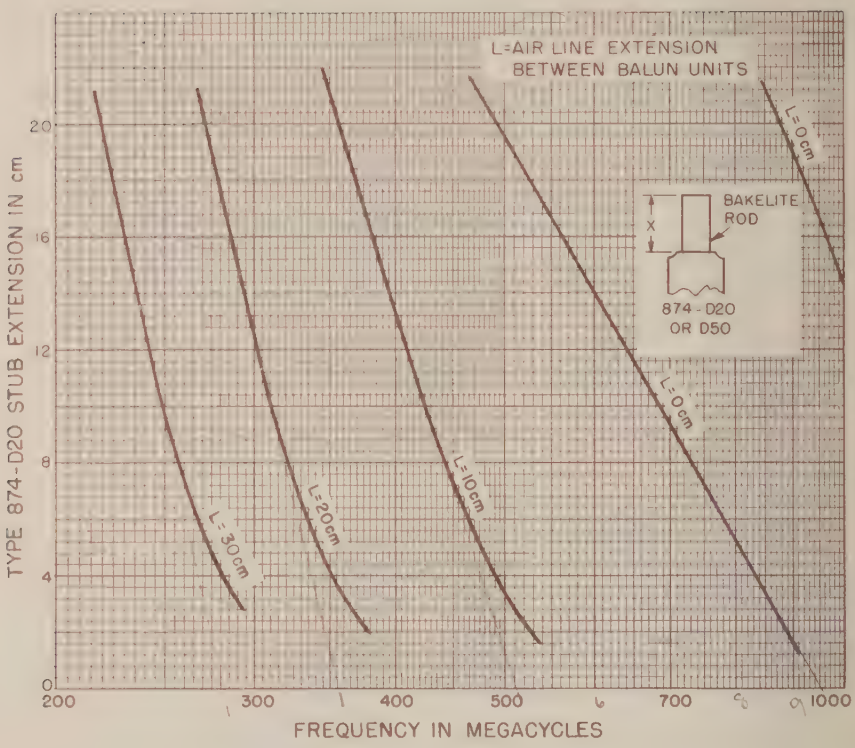



Figure 6b. Tuning ranges of the Type 874-UB Balun with the old style, uncalibrated Type 874-D20 Adjustable Stubs used as shunt tuning elements.

## 2.4 MEASUREMENT OF BALANCED CIRCUITS USING THE TYPE 1602-A ADMITTANCE METER ON A 300-OHM LINE

(1) Connect the Type 874-WO3 Open Circuit Termination to the admittance meter and balance. Note the SUSCEPTANCE and MULTIPLIER dial readings.

(2) Connect the Type 874-WO3 Short Circuit Termination to the admittance meter and balance.

(3) Determine from the chart in Figure 6 the length of airline sections and the tuning elements required for operation at the desired frequency, and insert these elements as indicated in Figure 1.

(4) Disconnect the Type 874-WN3 Termination and connect the balun without disturbing the settings of the arms on the admittance meter.

(5) Screw the short-circuiting plug into the far terminal, Number 2 of Figure 3, of the balun, and adjust the center tuning element, Number 1 until

the admittance meter indicates a balance. It may be necessary to readjust the CONDUCTANCE arm slightly to obtain a true null.

(6) Set the admittance meter arms to the positions at which a null was obtained in Step 1, remove the short-circuiting plug from balanced terminal Number 2, and adjust tuning element Number 2 until the admittance meter is balanced. The balun is now adjusted.

(7) Connect the balanced line to the terminal unit provided and plug the unit into the balun.

(8) Rebalance the admittance meter and determine the conductance and susceptance.

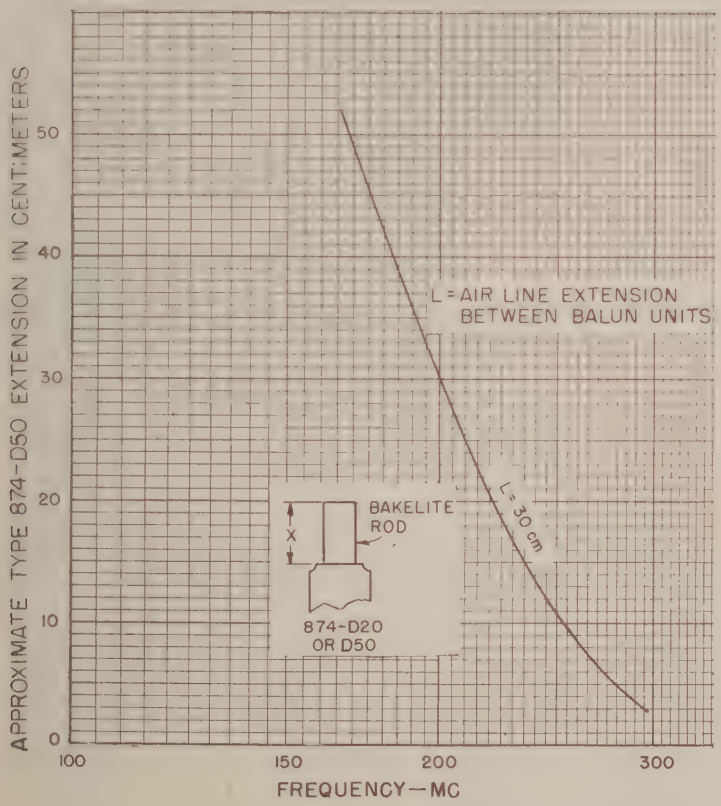



Figure 6c. Tuning ranges of the Type 874-UB Balun with Type 874-D50 Adjustable Stubs as shunt elements and Type 874-L30 Air Lines as series elements.

(9) Determine the electrical length of line, $\beta\ell$, between the point at which the admittance is actually measured and the balanced line. This is obtained from the open-circuit susceptance, $B_{oc}$, measured in Step 1 or the short-circuit susceptance $B_{sc}$ using the Smith chart or transmission-line equations. The best results are obtained when the condition producing the smallest susceptance is used. When the Smith chart is used, the measured susceptance is plotted on the chart and a line drawn through the point plotted and the center of the chart. (See Figure 7 and Paragraph 2.41.) The reading of the WAVELENGTHS TOWARD LOAD scale at the intersection of the line drawn is noted and if the open-circuit measurement was used, the distance in wavelengths from this point to the 0 point on the scale in a counter-clockwise direction is determined[1]; and if the short circuit measurement was used, the distance to the 0.25 point on the scale in a counter-clockwise direction is determined. This distance is the electrical length of the line in wavelengths. When transmission-line equations are used, the electrical length, $\beta\ell$, is determined from the equation:

$$\beta\ell = \tan^{-1} \frac{B_{oc}}{20}$$

$$= \tan^{-1} -\frac{20}{B_{sc}}$$

(10) Correct the measured admittance for the line length determined in Step 9, using a Smith chart or transmission-line equations as outlined in Paragraphs 2.3123 and 2.3124 in the instruction book for the Type 1602-A Admittance Meter. Then divide the result by 4 to obtain the admittance seen across the output terminals of the balun.

2.41 EXAMPLE

If a balanced circuit is measured at 600 Mc using the balun connected directly to the Admittance Meter, Type 874-D20 Adjustable Stubs and no series line sections are required for use with the balun, as indicated in Figure 6.

In Step 1 with the open circuit connected, the measured susceptance is + 7.4 x 5 = +37.0 mmhos; and the measured susceptance of the short circuit in Step 2 is -10.9 mmhos. After the balun has been adjusted, the unknown connected, and the Admittance Meter balanced, the measured admittance is (15.65 - j2.55) x 2 = 31.3 - j5.1.

The line length between the balun and the Admittance Meter is determined from the susceptance measurement with the short circuit connected

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[1] See Paragraph 2.3125 in the instruction book for the Type 1602-A Admittance Meter.

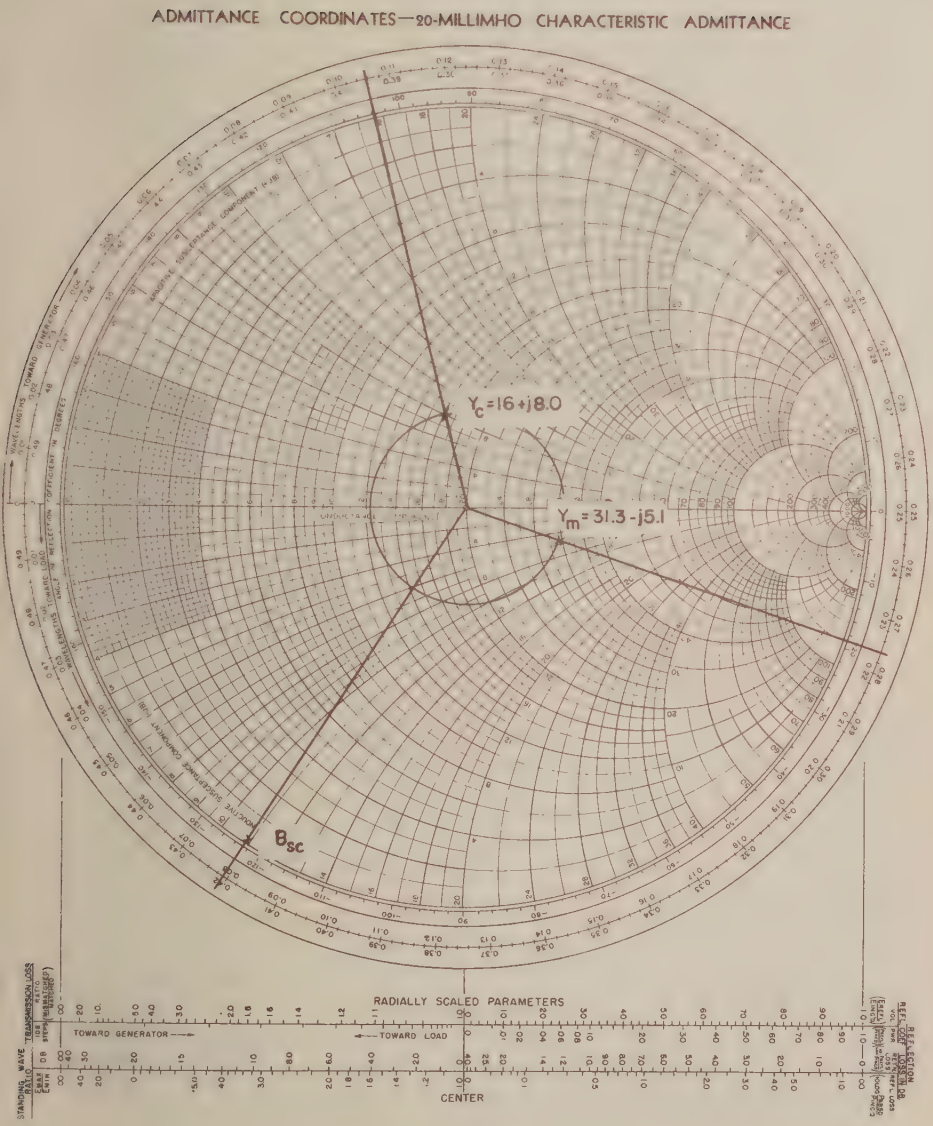


Figure 7. Smith Chart showing method of correcting for the length of 50-ohm coaxial line between the admittance meter and the balun.

(Step 2) by plotting the measured susceptance, −10.9 mmhos, on the Smith chart as shown in Figure 7. A line is drawn between the point plotted and center of the chart intersecting the WAVELENGTHS TOWARD LOAD. The distance is determined from the intersection, .0792 wavelengths, to the 0.25 wavelengths point in a counter-clockwise direction. The electrical line length is 0.25 − 0.0792 = 0.1708 wavelengths.

The admittance at the balun is determined by correcting for the 0.1708 wavelengths of 50-ohm coaxial line using the Smith chart. The measured admittance is plotted as shown in Figure 7, and a straight line is drawn through the point and the center of the circle intersecting the WAVELENGTHS TOWARD LOAD scale at 0.2238 wavelengths. When the electrical line length, 0.1708 is added to 0.2238, the result is 0.3946. A line is drawn through this point on the WAVELENGTHS TOWARD LOAD scale and the center of the chart. The distance from the center of the circle to the point corresponding to the measured admittance is determined using a scale or a compass to lay off an equal distance on the radial line just drawn. The coordinates of the point found, 16.0 + j8.0 mmhos, are the components of the admittance at the coaxial terminals of the balun. The admittance across the balanced terminals is 4.0 + j2.0 mmhos or 200 − j100 ohms.

## 2.5 MEASUREMENT OF THE IMPEDANCE OF BALANCED CIRCUITS USING THE TYPE 1602-A ADMITTANCE METER AND THE TYPE 874-LK CONSTANT-IMPEDANCE ADJUSTABLE LINE.

The line-length correction can be eliminated, and balanced admittance or impedance read directly from the admittance meter if the length of line between the admittance meter and the balun is adjusted to a quarter of half wavelength.

If the line is adjusted to a half wavelength, the admittance meter will measure the conductance and susceptance of the balanced circuit. The actual readings should be divided by four to account for the effect of the transformer.

If the line is adjusted to a quarter wavelength or an odd multiple thereof, the admittance meter will measure the resistance and reactance of the balanced circuit. The actual readings must be multiplied by 10 to account for the effect of the transformer (x4) and the quarter-wave line[2] (x2.5).

When the balanced impedance being measured is much larger than 300 ohms, the most accurate results will be obtained when a half-wave line is used and admittance is measured. When the balanced impedance is very small compared to 300 ohms, the most accurate results are obtained when

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[2]See Paragraph 2.3122 in the instruction book for the Type 1602-A Admittance Meter.

a quarter-wave line is used and impedance is measured. Either line length gives accurate results for balanced impedances of the order of 300 ohms.

The line length can be adjusted to the desired value by inserting a Type 874-LK Constant-Impedance Adjustable Line between the admittance meter and the balun. (Any "line stretcher" used must have a constant characteristic impedance throughout its length of serious errors will result. The Type 874-LK does have a constant characteristic impedance.) The proper adjustment is obtained by setting the CONDUCTANCE and SUSCEPTANCE indicators on the admittance meter at zero and the MULTIPLIER at unity and connecting a Type 874-WN3 or Type 874-WO3 Termination in place of the balun. The Type 874-WN3 Short Circuit Termination should be used if the line is to be adjusted to a quarter wavelength and the Type 874-WO3 Open Circuit should be used if the line is to be adjusted to a half-wavelength. The line length is then adjusted until the admittance meter is balanced. It may be necessary to adjust the CONDUCTANCE indicator slightly to obtain a complete null. After the balance is obtained, the adjustable line is locked by tightening the clamping collar on the line. When these steps have been carried out the line is adjusted to the proper length and measurements are made as outlined in Paragraph 2.4.

The actual steps are as follows.

(1) Connect the Type 874-LK Constant-Impedance Adjustable Line to the Admittance Meter.

(2) Set the CONDUCTANCE and SUSCEPTANCE indicators at zero and the MULTIPLIER at unity.

(3) Connect a Type 874-WN3 Short Circuit or a Type 874-WO3 Open Circuit at the far end of the line stretcher. The short circuit is used if the line is to be adjusted to a quarter wavelength and the open circuit is used if the line is to be adjusted to a half wavelength. (See previous discussion.)

(4) Adjust the line stretcher until the admittance meter is balanced. It may be necessary to adjust slightly the CONDUCTANCE indicator to obtain a complete null. If the range of adjustment of the line stretcher is insufficient, add sections of Type 874-L20 Air Line until the proper length can be obtained[3].

(5) If a quarter-wave line is used, follow Steps 1 through 8 found in Paragraph 2.4. Step 2 can be omitted and the CONDUCTANCE and SUSCEPTANCE indicators set at zero and the MULTIPLIER at unity before going on to Step 3. If a half-wave line is used, Steps 2 through 8 of Paragraph 2.4

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[3]In some cases, the necessity for adding lengths of line can be eliminated or the amount of line required can be reduced if a quarter- rather than a half-wave condition or vice versa is used.

should be followed. Step 1 is omitted. In Step 6 set the CONDUCTANCE and SUSCEPTANCE indicators at zero and the MULTIPLIER at unity.

(6) If a quarter-wave line is used the resistive and reactive components of the impedance appearing across the balanced terminals of the balun are the CONDUCTANCE and SUSCEPTANCE dial readings multiplied by the setting of the MULTIPLIER and by the factor 10. If a half-wave line is used, the conductive and susceptive components of the admittance appearing across the balanced terminals are the CONDUCTANCE and SUSCEPTANCE dial readings multiplied by the setting of the MULTIPLIER and divided by the factor 4.

The measured impedance of admittance is that present across the balanced terminals of the balun, (terminals Numbers 1 and 2 in Figure 3.) The terminals are connected to the unknown circuit by means of the Type 874-UB-P1 300-ohm Terminal Unit. This unit is equivalent to a section of 300-ohm line 3.9 cm in length.

### 2.51 EXAMPLE

If the balanced circuit, used as an example in Paragraph 2.41 is measured at 600 Mc using the Admittance Meter and the line stretcher, set to a quarter-wavelength condition, the following procedure is used. The Admittance Meter is set to balance at zero, the short-circuit termination connected to the end of the line stretcher in place of the balun, and the line stretcher adjusted until a null is obtained. The line stretcher is then locked, the open circuit substituted for the short circuit and the Admittance Meter controls. The dial readings are G = 0.9, B = −17.0, and the multiplier is 10.

From Figure 6, it is determined that the balun can be tuned to 600 Mc using two Type 874-D20 Adjustable Stubs and no additional series elements. These units are connected to the balun, the balun connected to the line stretcher, the Number 2 balun terminal shorted by means of the threaded plug provided, and the Admittance Meter set to 0 + j0 and unity multiplier. The center tuning Stub, Number 1 is then adjusted until a null is obtained. A slight adjustment of the conductance arm is necessary to obtain a true null.

The Admittance Meter is then set to the admittance previously measured with the open circuit connected, the short-circuiting plug removed, and the end tuning stub, Number 2, adjusted until a null is obtained. The conductance arm will need to be adjusted slightly to obtain a true null. The balun is now adjusted.

The line under test is then connected to the 300-ohm terminal unit which in turn is inserted into the balanced jacks in the balun. The Admittance Meter is then balanced using its controls and the measured admittance is 20 − j10. The impedance appearing across the balun terminals is therefore 200 − j100 ohms.

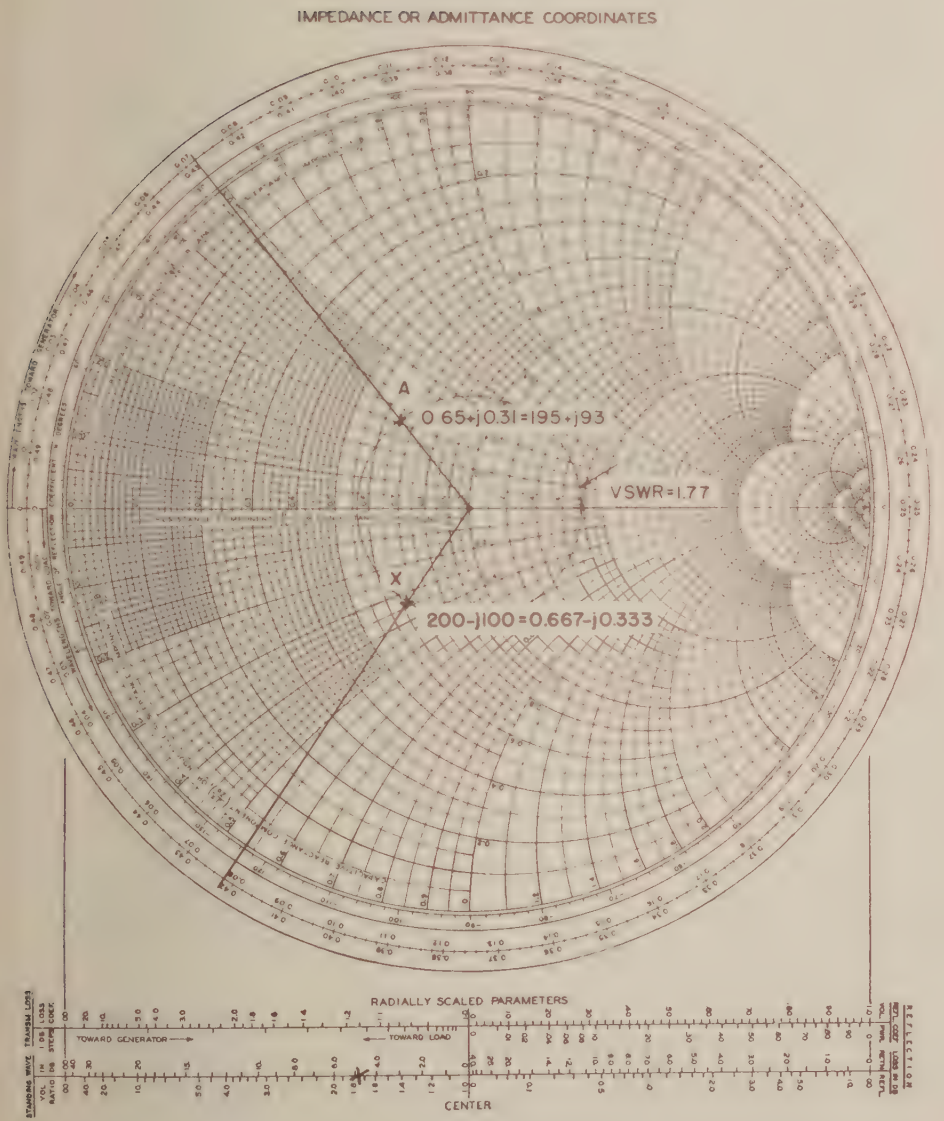



Figure 8. Smith Chart showing method of correcting for ne length of 300-ohm line between the balanced terminals and the point at which the impedance is desired.

## 2.6 DETERMINATION OF IMPEDANCE AT OTHER POINTS ALONG THE 300-OHM LINE

The impedance or admittance at the actual point of connection of the balanced line under text to the 300-ohm terminal unit or at any other point along the balanced line, can be determined from a knowledge of the following factors: the measured impedance or admittance, the electrical line length between the point at which the impedance is known and the point at which is desired, and the characteristic impedance of the line. Smith charts or transmission-line equations can be used for this calculation.

### 2.61 LINE-LENGTH CORRECTION USING THE SMITH CHART

Correction for the length of line between the point at which the instrument measures the admittance and the point at which the measurement is desired can be easily made through the use of the normalized Smith chart, a copy of which is shown in Figure 8. This chart is drawn for normalized admittances or impedances, that is, the impedance divided by the characteristic impedance divided by the characteristic impedance of the line or the admittance divided by the characteristic admittance of the line. A slide rule version of the normalized chart is available from the Emeloid Corporation, Hillside, New Jersey.

Corrections for line length are made as follows:

(1) Divide the measured admittance by the characteristic admittance or the measured impedance by the characteristic impedance and find the point on the chart corresponding to the normalized real and imaginary components.

(2) Draw a line through this point and the center of the chart. The line should extend to intersect the WAVELENGTHS TOWARD LOAD scale on the outer edge of the chart as shown in Figure 8.

(3) Determine the reading of the WAVELENGTHS TOWARD LOAD scale at its intersection with the straight line drawn.

(4) Add the effective electrical length, in wavelengths, of the line for which corrections are being made, to the scale reading and find the point on the WAVELENGTHS TOWARD LOAD scale corresponding to the sum.

(5) Draw a radial line from the point found in Step 4 to the center of the chart.

(6) Measure the distance from the center of the chart to the point plotted in Step 1 and lay off an equal distance from the center of the chart along the line drawn in Step 5.

(7) Determine the coordinates of the point found and if the chart is being used for admittance multiply the normalized conductance and susceptance values found on the chart by the characteristic admittance of the line. If impedance is used, multiply the coordinates by the characteristic impedance. The results are the admittance or impedance appearing at the point in question.

The radial distance from the center of the chart to the points corresponding to the measured admittance and the unknown admittance is a func-

tion of the standing-wave ratio. The VSWR corresponding to a certain distance can be determined from the scale located at the lower left corner of the figure.

For example, if the measured impedance is 200 - j100 ohms and the electrical length of line between the point at which the impedance is desired and the point at which the balanced impedance is measured at the actual terminals of the balun is 0.35 wavelengths, the calculation can be carried out as indicated in Figure 8. The normalized measured impedance is 0.667 - j0.333. The point X corresponds to this impedance and the line drawn through this point and the center of the circle intersects the WAVELENGTHS TOWARD LOAD scale at 0.078. The second line is then drawn through the center of the circle and the point 0.078 + 0.35 = 0.428 on the WAVELENGTHS TOWARD LOAD scale. The coordinates of the point, A, are 0.65 + j0.31 = 195 + j93 ohms, the components of the unknown impedance.

## 2.62 LINE-LENGTH CORRECTIONS USING TRANSMISSION-LINE EQUATIONS

A tedious but more accurate method of correcting for line length is through the use of transmission-line equations. The impedance $Z_x$ or admittance $Y_x$ at a point a distance $\ell$ wavelengths from the point at which the impedance $Z_m$ or admittance $Y_m$ is measured can be calculated from the equation:

$$Z_x = Z_o \times \frac{Z_m - jZ_o \tan \beta\ell}{Z_o - jZ_m \tan \beta\ell}$$

$$Y_x = Y_o \times \frac{Y_m - jY_o \tan \beta\ell}{Y_o - jY_m \tan \beta\ell}$$

where $Z_o$ and $Y_o$ are the characteristic impedance and characteristic admittance respectively of the line under test. The above equations assume that the line is lossless.

## 2.63 DETERMINATION OF THE ELECTRICAL LENGTH OF THE BALANCED LINE

In the general case the electrical length of line between the point at which the impedance or admittance is desired and the point it is measured at the balun terminals can be determined by short- or open-circuiting the line at the point at which the measurement is desired and measuring the reactance, $X_{oc}$ or $X_{sc}$, or the susceptance, $B_{oc}$ or $B_{sc}$. The electrical length can be determined by plotting the normalized reactance or susceptance and drawing a line (which intersects the WAVELENGTHS TOWARD LOAD scale) through the point and the center of the chart. If the line is

short-circuited and reactance is measured or if the line is open-circuited and susceptance measured, the electrical line length is the distance along the WAVELENGTHS TOWARD LOAD scale between the intersecting point and 0 on the scale in a counter-clockwise direction. If the line is open-circuited and reactance is measured or short-circuited and susceptance measured, the electrical line length is the distance along the WAVELENGTHS TOWARD LOAD scale and the 0.25 point on the scale in a counter-clockwise direction.

For example, if the measured short-circuit reactance is -414 ohms, or when normalized -1.38, the electrical line length is 0.350 wavelengths as shown in Figure 9.

In the method outlined above, the line length may be an integer number of half wavelengths longer than calculated. However, if the line is lossless, the half-wavelength sections omitted will have no effect on the impedance transformation produced by the line.

## 2.7 DETERMINATION OF VSWR ON BALANCED LINE

The VSWR on the balanced line can be determined from the impedance or admittance appearing across the balanced terminals of the balun using a normalized Smith chart or transmission-line equations.

If the Smith chart is used, the measured impedance or admittance is normalized and plotted on the chart. The distance from the center of the chart to the point plotted is measured and laid off either on the scale marked STANDING WAVE RATIO located at the lower left section of the chart, or on the resistance component axis of the chart starting from the center and travelling toward the right. The VSWR expressed as a ratio or in db can be determined from the lower scales, and the reading of the normalized resistance scale is equal to the VSWR expressed as a ratio.

For instance in the example plotted in Figure 8, the VSWR determined from the lower scales is 1.77 or 4.9 db. and 1.77 when determined from the resistance axis.

The VSWR can also be calculated from the following equations:

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

where

$$|\Gamma| = \left|\frac{Z_m - Z_o}{Z_m + Z_o}\right| = \left|\frac{R_m - Z_o + jX_m}{R_m + Z_o + jX_m}\right|$$

$$= \left|\frac{Y_o - Y_m}{Y_o + Y_m}\right| = \left|\frac{Y_o - G_m - jB_m}{Y_o + G_m + jB_m}\right|$$

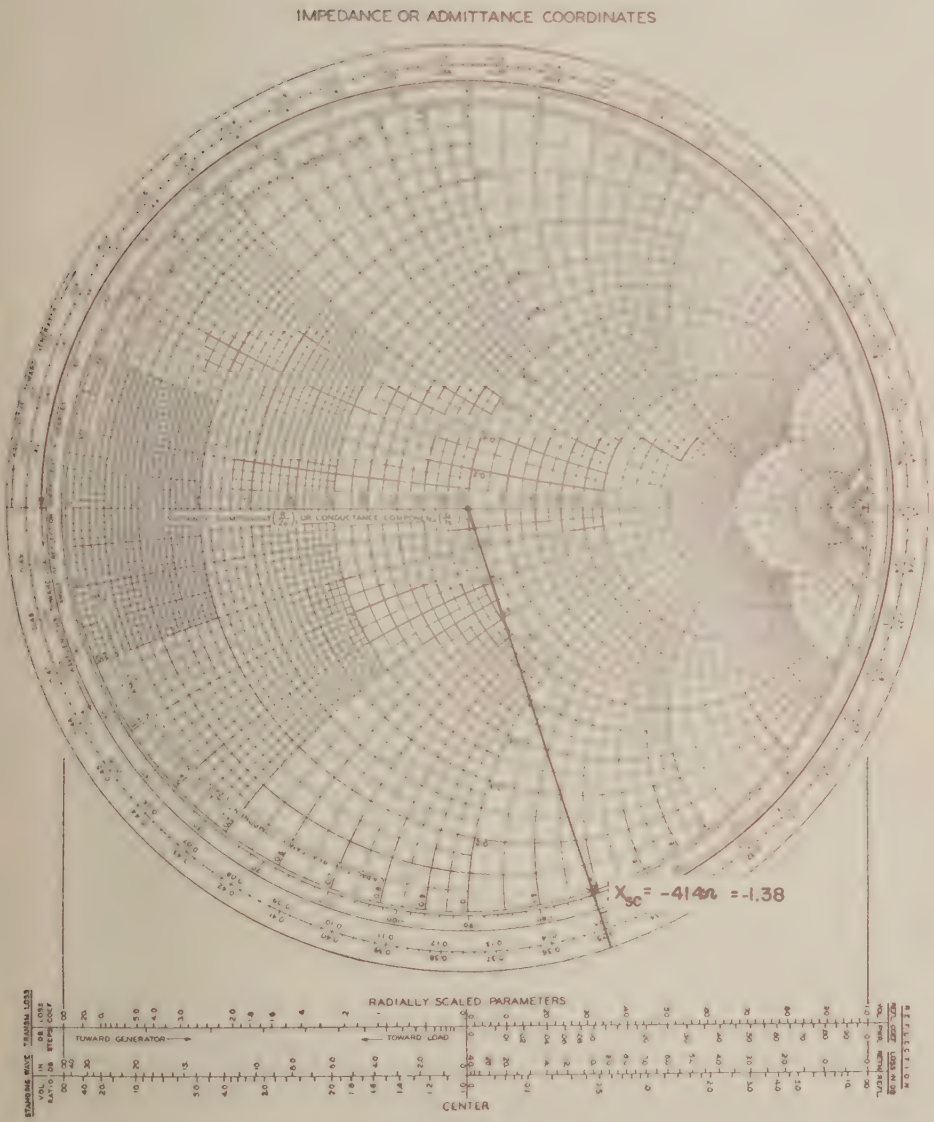



Figure 9. Smith Chart showing method of determining the electrical length of line between the balanced terminals and the point along the 300-ohm line at which the impedance is desired using the reactance measured with the line short-circuited.

where $R_m$ and $X_m$ are the components of the measured balanced impedance $Z_m$, and $G_m$ and $B_m$ are the components of the measured balanced admittance $Y_m$. $Z_o$ and $Y_o$ are the characteristic impedance and admittance respectively of the balanced line, $Z_o = 300$ ohms, $Y_o = 3.33$ mmhos.

## 2.8 BALANCED LINE MEASUREMENTS USING THE TYPE 874-LB SLOTTED LINE

The Type 874-LB Slotted Line can also be used with the Type 874-LB Balun to measured balanced circuits. The procedure is very similar except that the impedance is determined from measurements of the VSWR on the 50-ohm coaxial line, and the position of a voltage minimum with respect to the load. The procedure is as follows:

(1) Connect the Type 874-WO3 Open-Circuit Termination to the end of the slotted line. Determine and record the position of the voltage minimum nearest the load end of the slotted line.

(2) Replace the open circuit with a Type 874-WN3 Short-Circuit Termination and again determine and record the position of voltage minimum nearest the load end of the slotted line.

(3) Determine from Figure 6 the series and shunt tuning elements required for tuning the balun to the desired frequency and insert these elements.

(4) With the probe set at the minimum found in Step 2, replace the short circuit with the balun. Short circuit to ground the balun terminal farthest from the coaxial input by screwing into the hole the threaded plug attached to the balun.

(5) Adjust the tuning element located at the center of the balun until a minimum indication is obtained from the indicator attached to the probe on the slotted line. Then check the position of the minimum by sliding the probe on the slotted line. If the minimum does not occur at the setting obtained in Step 2, readjust the tuning element until it does. This second operation is only necessary when the balun losses are fairly large or the generator badly mismatched to the characteristic impedance of the coaxial line, and in most cases it can be omitted.

(6) Remove the short-circuiting plug from the balun, set the probe at the position found in Step 1, and adjust the tuning element nearest the balanced terminals until a minimum is obtained as in Step 5. The actual position of the minimum should be checked as outlined in Step 5.

(7) Connect the unknown line to the Type 874-UB-P1 300-ohm Terminal Unit and plug the unit into the balanced balun terminals.

(8) Measure the VSWR and the position of the voltage minimum nearest the load.

(9) Find the point on the resistance axis of the Smith chart corresponding to the VSWR.

(10) Determine the distance in centimeters between the voltage minimum

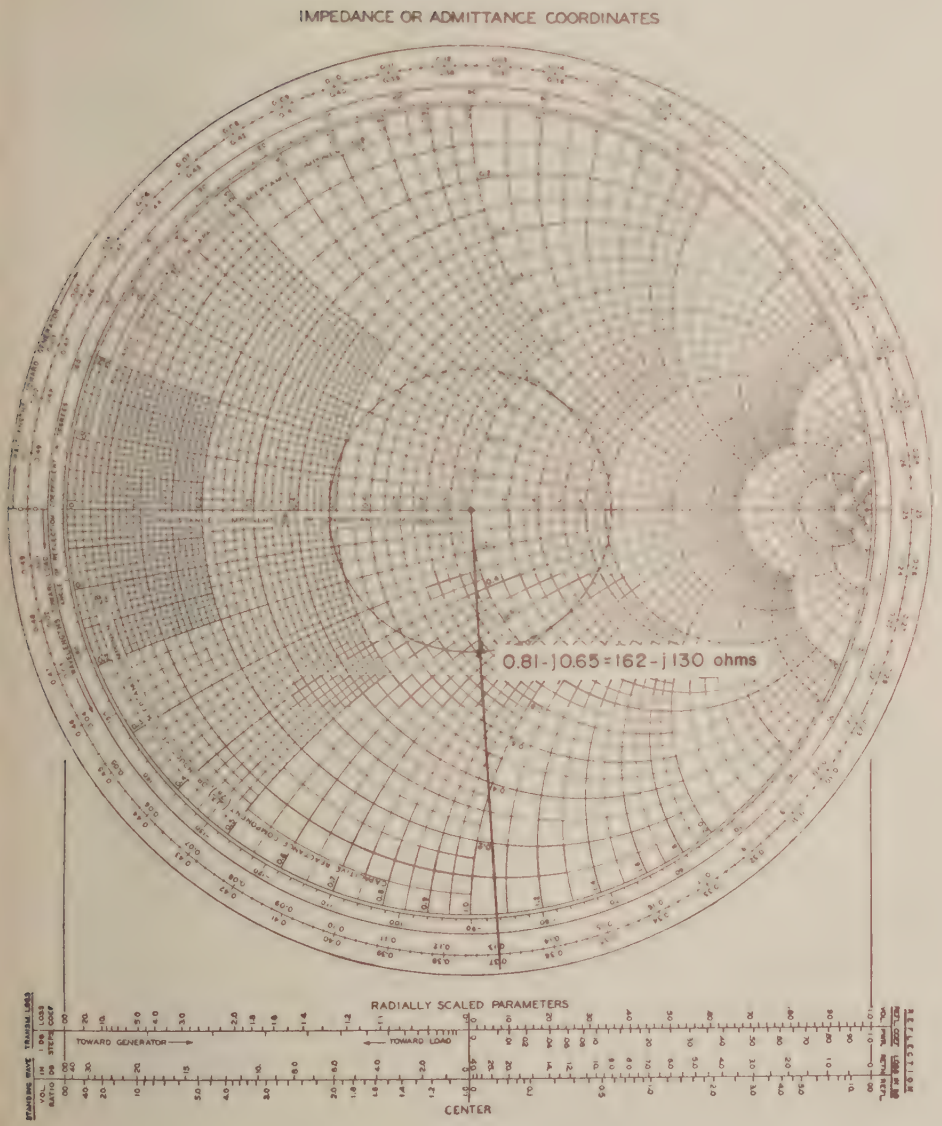



Figure 10. Smith Chart showing method of determining balanced impedance from the VSWR and the position of the voltage minimum.

found in Step 2 and the minimum found in Step 8. Determine whether the minimum found in Step 2 is on the load or generator side of the minimum found in Step 8.

(11) Divide the distance found in Step 10 by the wavelength and find the corresponding reading on the appropriate scale found along the circumference of the chart. If in Step 10 the minimum of Step 2 was found to be on the load side of the minimum of Step 8, use the WAVELENGTHS TOWARD LOAD scale. If the minimum was on the generator side, use the WAVELENGTHS TOWARD GENERATOR scale.

(12) Draw a line from the point found in Step 11 to the center of the chart; draw a circle through the point found in Step 9 with the center at the center of the chart. Determine the coordinates of the intersection of the straight line and the circle.

(13) Multiply the coordinates by 50 to obtain the actual input impedance to the balun, or by 200 to obtain the impedance appearing across the balanced terminals.

2.81 EXAMPLE

If an antenna fed by a 300-ohm balanced line is measured at 600 Mc ($\lambda$ = 50 cm) the position of the voltage minimum with the open circuit connected is 35.00 cm and with the short circuit connected 47.50 cm. (The load is connected to the right hand end of a Type 874-LB Slotted Line.) After the balun is adjusted and the load connected, the measured VSWR is 2.1 and the position of the minimum is at 41.00 cm. The minimum with the short circuit connected is 6.50 cm or 0.130 wavelengths on the load side of the minimum with the load connected. The Smith chart is used to calculate the impedance appearing across the input to the balun as indicated in Figure 10. The WAVELENGTHS TOWARD LOAD scale is used in this case and the normalized impedance is 0.81 – j0.65. The balanced impedance therefore is 162 – j130 ohms.

The VSWR on the 300-ohm line in this case can be determined as outlined in Paragraph 2.7 and is 2.3.

## 2.9 MEASUREMENT OF BALANCED LINES HAVING CHARACTERISTIC IMPEDANCES DIFFERING FROM 300 OHMS

The basic balun measures the impedance appearing directly at its terminals and hence the characteristic impedance of the line does not enter into the measurement. However in order to eliminate the effect of stray terminal capacitances and inductances, a terminal unit is provided which lumps these reactances into a short section of transmission line. The Type 874-UB-P1 300-ohm Terminal Unit proportions these reactances to form a section of 300-ohm transmission line 3.9 cm long.

If transmission lines having characteristic impedances differing from 300 ohms are measured, the transformation produced by the short section

of 300-ohm line in the terminal unit can be corrected for as outlined in Paragraph 2.7, and the actual input impedance to the line under test determined. Also another terminal unit can be designed which has the desired characteristic impedance.

## 2.10 USE OF THE BALUN TO OBTAIN A BALANCED VOLTAGE SOURCE

The Type 874-UB Balun can be used to convert an unbalanced voltage source to a balanced one. However it is not too well suited for many signal generator applications, because when the unbalanced source impedance is 50 ohms, the balanced output impedance obtained is 200 ohms rather than 300 ohms. In cases in which the output impedance is not critical, the balun will provide a very well-balanced voltage source. For the best results the balun should be adjusted using an impedance-measuring instrument. However if such a device is not readily available satisfactory results can usually be obtained if the tuning elements are adjusted to the positions indicated in Figure 6.

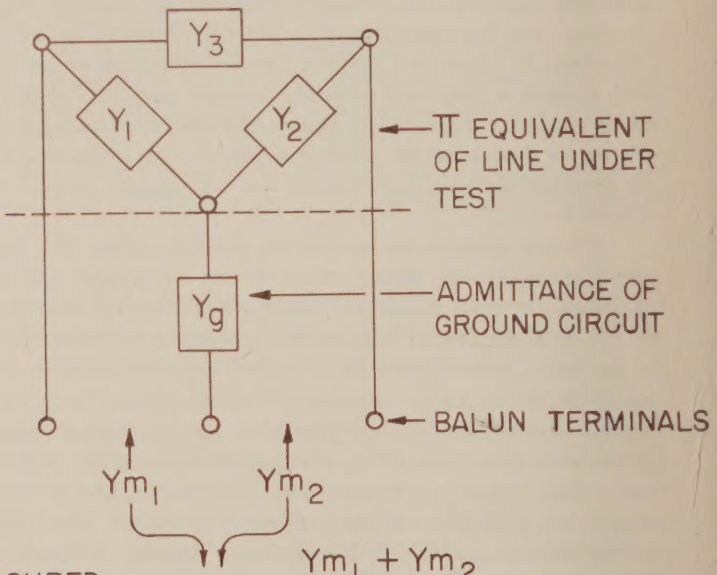
If spot frequencies are to be checked using the balun the junction block assembly and tuning elements can be omitted and sections of cable of various lengths connected directly between the connectors on the back of the terminal block. The cables, including the short sections of air line in the balun, should have an electrical length equal to a half wavelength at the operating frequency. The length can be checked using an impedance measuring device or by short circuiting balun terminal Number 2 using the threaded plug and connecting a voltmeter between the balun terminal nearest the coaxial input and ground. The generator should be connected and voltmeter indication noted as the frequency is varied. The line length is correct at the frequency at which the voltmeter reading is a minimum. For best results the connector used for the tuning element on the balun terminal block and the center conductor in the short section of line feeding the connector should be removed when a true half-waveline is used.

## 2.11 EFFECT OF UNBALANCE IN CIRCUIT UNDER TEST

If the circuit under test is not exactly balanced, the characteristics of the circuit cannot be exactly described by a single impedance measurement. The circuit can be considered as a three-terminal unsymmetrical device as shown in Figure 11. The performance of an unbalanced line when connected to a balanced source will be affected by the impedance $Z_g$ or admittance $Y_g$ in the neutral lead.

The neutral point in the Type 874-UB Balun is securely tied to ground and if the circuit under test is unbalanced, current will flow in the neutral connection through the impedance of the ground system and affect the measurements as indicated in Figure 11. For small unbalances, the effects on the measurements are usually negligible. If the unbalance is appreciable,

it can be detected by touching the balun and other parts of the measuring circuit and noticing the effect on the measured impedance. If the measured impedance does not change significantly when various grounded parts are touched, the circuit under test is well balanced. If a significant change occurs, the circuit under test is unbalanced.




EFFECTIVE MEASURED BALANCED ADMITTANCE $= Ym_e = \dfrac{Ym_1 + Ym_2}{4}$

$$Ym_e = Y_3 + \frac{Y_1 Y_2}{Y_1 + Y_2} \times \frac{1 + \dfrac{Y_g}{4}\,\dfrac{Y_1 + Y_2}{Y_1 Y_2}}{1 + \dfrac{Y_g}{Y_1 + Y_2}}$$

IF LINE IS BALANCED, $Y_1 = Y_2$, AND

$$Ym_e = Y_3 + \frac{Y_1}{2}$$

Figure 11. Effect of unbalance in circuit under test on admittance measurement.